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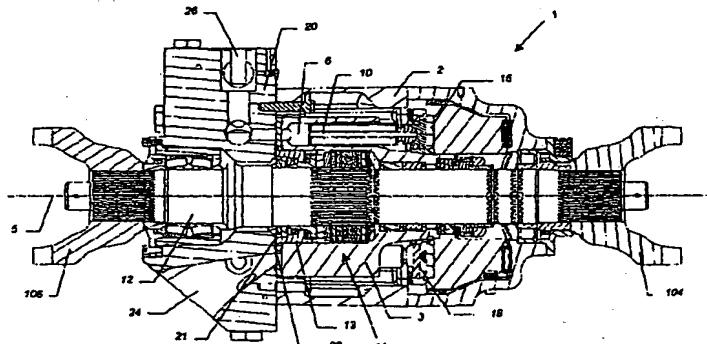
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(54) Title: DECOUPLING MECHANISM FOR HYDRAULIC PUMP/MOTOR ASSEMBLY



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(57) Abstract: A positive displacement hydraulic pump/motor assembly (1) includes a rotary cylinder block (3) having a central axis (5) and a generally circular array of cylinders (6) disposed around the axis. A corresponding plurality of pistons (10) is reciprocably disposed within the respective cylinders. A drive shaft (12) extends through a bore (13) formed in the cylinder block to effect rotation of the cylinder block about the central axis. A drive plate (15) is disposed at one end of the cylinder block to effect sequentially staggered reciprocation of the pistons in response to rotation of the cylinder block. A stationary valve plate (20) is disposed at an opposite end of the cylinder block, the valve plate having a valve face (21) adapted for sliding rotational engagement with a complementary mating face (22) formed on the cylinder block. The valve plate further includes at least one inlet port (24) for fluid communication with a source of hydraulic fluid and at least one outlet port (26) for fluid communication with a hydraulic load. The ports are disposed such that in use, hydraulic fluid is progressively drawn into the cylinders in sequence as the respective pistons are displaced away from the valve plate and subsequently expelled from the cylinders as the pistons are progressively displaced toward the valve plate. The pump/motor assembly further includes a selectively releasable decoupling mechanism (14) adapted in an engaged mode to connect the drive shaft to the cylinder block and in a disengaged mode to allow the drive shaft to rotate substantially independently of the cylinder block.



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TITLE: DECOUPLING MECHANISM FOR HYDRAULIC PUMP/MOTOR ASSEMBLY

FIELD OF INVENTION

5 The present invention relates generally to hydraulic motors and pumps, and more particularly to positive displacement axial piston motors and pumps.

The invention has been developed primarily for use with a pump/motor assembly which forms part of a regenerative drive system ("RDS"), and will be described predominantly hereinafter in that context. It should be appreciated, however, 10 that the invention is not limited to this particular field of use, being readily adaptable to any axial piston hydraulic motor or pump for use in virtually any application.

BACKGROUND OF THE INVENTION

In the present context, the invention has been developed more specifically as 15 an improvement to the RDS described by the present applicant in an earlier patent application filed via the Patent Cooperation Treaty (PCT) as international application No PCT/AU99/00740, the full contents of which are hereby incorporated by reference.

As previously described in that earlier patent application, the RDS is based 20 upon a positive displacement pump/motor arrangement incorporating a cylinder block which houses a cylindrical array of axially reciprocating pistons. In one preferred embodiment, the cylinder block and valve face are coaxially disposed around the primary drive shaft, thereby avoiding the need for intermediate gearing, chains, belts or other transmission elements. When used in conjunction with a suitable 25 accumulator, the resultant regenerative drive system provides a system for harnessing the previously wasted braking energy of a vehicle, storing this energy, and subsequently releasing it back into the drive train as required under conditions of acceleration, load, or gear change transitions.

This RDS arrangement significantly improves the overall efficiency of the 30 engine and power transmission systems of the vehicle. The RDS system also conveniently acts as an efficient auxiliary braking mechanism in the energy accumulation mode. The system as described, however, is subject to several

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significant limitations, many of which are common to previously known axial piston hydraulic motors and pumps.

One significant limitation in the pump/motor assembly as previously described, relates to the inherent drag associated with the seals, bearings, valve faces and other elements that are in direct sliding contact with each other. In particular, this drag comes into play as the cylinder block and other components in the rotational group rotate with respect to the valve plate, housing and other stationary components of the system. In the specific pump/motor unit described, these frictional drag forces are reduced by virtue of the fact that most of the components in direct contact with one another "float" on a film of oil, which is ideally pressurised. Nevertheless, a residual drag factor remains, which consumes energy, generates heat, and compromises the potential efficiency of the system.

From this perspective, the present invention is concerned more specifically with the drag normally attributable to the direct communication between the rotational group including the cylinder block, and the valve plate. In the pump/motor assembly and RDS unit as previously described in the earlier referenced patent application and other pumps of this type, a "hold-down" spring is disposed resiliently to bias the cylinder block axially into face-to-face sliding engagement with the valve plate. Because of the relatively high pressures generated within the pump/motor assembly, the hold-down spring is required to exert a relatively high degree of axial force on the cylinder block in order to prevent excessive fluid leakage between the block and the valve plate, particularly under conditions of maximum pressure or power transmission.

While effective in preventing excessive leakage, the relatively high axial force between the cylinder block and the valve plate causes significant frictional drag between these components as they slide rotationally relative to one another, separated only by a thin film of pressurised oil. From an overall system perspective, the associated inefficiency is proportionally more significant in situations where the pump/motor unit is operating in a neutral or "free-wheel" mode. This is because in that condition, the unit is neither pumping nor driving and is therefore doing no real work against which its own inherent inefficiency can be offset, and must nevertheless

continue to rotate, often at high speed, as a result of its direct connection with the rotary power source.

While applying to some extent in almost any application of hydraulic motors and pumps, this limitation is particularly significant in the context of an RDS unit 5 fitted to a vehicle, in the manner previously described. That is because in many situations, the RDS may "free-wheel" for prolonged periods. During this time, the unit would generate neither motor nor pump pressure, but would nevertheless continue to rotate at the same speed as the vehicle driveline to which it is integrally connected. This would predominantly occur, for example, during long runs on open highways 10 with minimal changes in traffic conditions or road topography. In such situations, the RDS may do no effective work for prolonged periods, and yet introduce an inherent drag factor into the driveline, the parasitic losses from which ultimately compromise the efficiency of the power train of the vehicle.

The basic problem is in fact compounded in such conditions, because the drag 15 factor itself is exacerbated when the pump/motor unit is operating in the neutral or free-wheeling mode. This is because the unit is not producing hydraulic pumping pressure at a level sufficient to sustain the film of hydrostatic pressurised oil required to minimise the effect of frictional drag between the components in face-to-face rotational contact with one another. In such circumstances, an internal or external 20 charge pump may be utilised to supply a 'pilot' oil pressure, so as to maintain lubrication between these components. However, this merely translates the problem, in the sense that additional energy is then consumed in running the supplementary charge pump. The same situation applies if a pilot pressure for lubrication is created by a small non-zero swash plate angle, or drawn from the accumulators.

25 Drag is also exacerbated in such applications due to the fact that the cylinder barrel rotates in an oil bath within a housing. While the oil bath provides necessary cooling and lubrication, it is also itself a source of hydro-dynamic drag on the integral drive line, which is an ongoing cause of energy loss and hence inefficiency, again of particular significance when the pump/motor unit is doing no work in the free- 30 wheeling mode.

The foregoing discussion of the prior art is intended solely to place the invention in an appropriate context, and allow a proper appreciation of its technical

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significance. Any statements made in this specification about prior art information should not be construed as admissions that such information is widely known, or forms part of common general knowledge in the relevant field.

It is an object of the present invention to overcome or substantially ameliorate 5 one or more of the deficiencies of the prior art, or at least to provide a useful alternative.

DISCLOSURE OF THE INVENTION

Accordingly, the invention provides a positive displacement hydraulic pump/motor assembly including:-

- 10 a rotary cylinder block having a central axis and incorporating a generally circular array of cylinders disposed in parallel relationship around the axis;
- 15 a corresponding plurality of axial pistons reciprocably disposed within the respective cylinders;
- 20 drive means including a drive shaft extending through a bore formed in the cylinder block to effect rotation of the cylinder block about the central axis;
- 25 a drive plate disposed at one end of the cylinder block to effect sequentially staggered reciprocation of the pistons in response to rotation of the cylinder block;
- 30 a stationary valve plate disposed at an opposite end of the cylinder block, the valve plate having a valve face adapted for sliding rotational engagement with a complementary mating face formed on the cylinder block;
- 35 the valve plate further including at least one inlet port adapted for fluid communication with a source of hydraulic fluid and at least one outlet port adapted for fluid communication with an hydraulic load;
- 40 the ports being disposed such that in use, hydraulic fluid is progressively drawn into the cylinders in sequence as the respective pistons are displaced away from the valve plate and subsequently expelled from the cylinders as the pistons are progressively displaced toward the valve plate;
- 45 the pump/motor assembly further including a selectively releasable decoupling mechanism adapted in an engaged mode to connect the drive shaft to the cylinder block and in a disengaged mode to allow the drive shaft to rotate substantially independently of the cylinder block.

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It will be appreciated that the same assembly may be used in one mode as a motor, and in another mode as a pump. It should therefore be understood that throughout the specification, these terms may be used in conjunction, or interchangeably. In each case, however, unless the context clearly dictates otherwise,

5 any reference to configuration of the invention as a pump should be understood to include configurations as a motor, and vice versa. It should also be understood that the inlet and outlet ports may alternate in function according to the mode of operation of the unit.

It should further be understood that the terms "sealing", "sealing engagement" 10 and the like are intended to convey the sense of prevention of excessive leakage past or through the relevant components. It will be appreciated, however, that in a system of this nature, a minimal level of leakage flow may persist, and indeed maybe desirable for lubrication purposes, notwithstanding the fact that effective sealing, in the intended sense, has been achieved.

In a particularly preferred embodiment of the invention, the positive 15 displacement pump/motor is a swash plate type unit. In this embodiment, the drive plate takes the form of a stationary swash plate, which is inclined with respect to the central rotational axis of the cylinder block. Preferably also, the ends of the pistons remote from the valve plate include "followers" adapted to slide over the swash plate 20 as the cylinder block rotates. A hold-down plate is preferably disposed to capture the floating ends of the pistons and retain the followers in sliding contact with the swash plate. In alternative embodiment, however, springs or other suitable means may be used to retain the followers in contact with the swash plate.

Preferably, the angle of inclination of the swash plate is selectively adjustable, 25 to provide variable flow rate characteristics. In particular, the swash plate is preferably adapted to be selectively inclined in a positive or a negative sense, thereby enabling the assembly alternately to operate as a motor or a pump. Most preferably, the variable swash plate can also be oriented in an intermediate or neutral position, effectively normal to the central axis, such that rotation of the cylinder block causes 30 no movement of the pistons, hence induces no net flow into or out of the cylinders through the ports, and therefore causes no load on the system aside from a residual level of inherent frictional drag.

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In other embodiments, it will be appreciated that the invention may also be applied to a bent axis type hydraulic pump. In that case, connecting rods for the pistons are pivotably attached to a thrust plate adapted to rotate with the cylinder block. The invention may also be adaptable to other configurations of motors and pumps.

5 Preferably, the pump/motor assembly further includes bias means disposed to apply a bias force urging the respective mating faces on the cylinder block and the valve plate into sealing engagement.

In the preferred embodiment, the decoupling means include a clutch mechanism, desirably in the form of a multi-plate clutch disposed coaxially around the 10 drive shaft. The clutch desirably acts between the drive shaft and the cylinder block, so as to selectively transmit rotary drive therebetween.

Preferably, the multi-plate clutch includes a stack of inter-leaved inner and outer clutch plates adapted for splined engagement with the drive shaft and cylinder block respectively.

15 Preferably, compression of the clutch stack promotes frictional engagement of the inner and outer clutch plates to enable transmission of torque between the shaft and cylinder block.

Preferably, the clutch includes a piston assembly configured selectively to compress the plates in the stack in order to activate or engage the clutch. Preferably, the 20 piston assembly is non-rotating. Preferably, the piston assembly is configured for shaft-to-shaft reaction, thereby substantially isolating compressive loads from the shaft-end bearings.

Preferably, the clutch is able to be completely deactivated, thereby to provide for independent rotation of the shaft and the cylinder block. Preferably, the clutch is 25 also capable of partial activation, to transmit a selected proportion of torque between the shaft and cylinder block. Preferably, the clutch is progressively and controllably actuatable between the engaged and disengaged modes of operation. Preferably, the multi-plate clutch is of a wet type design.

In one particularly preferred application, the invention as defined is adapted 30 for incorporation into an energy management system operable in a driving mode, a braking mode and a neutral mode, the energy management system including:-

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energy accumulation means operable selectively to store and release energy through controlled receipt and release of hydraulic fluid;

a positive displacement hydraulic pump/motor assembly as defined above, in fluid communication with the energy accumulation means;

5 a low pressure hydraulic reservoir in fluid communication with the pump/motor assembly; and

connection means for connecting the pump/motor assembly to a drive line;

the system being arranged such that in the braking mode the pump/motor assembly retards the drive line by pumping hydraulic fluid into the accumulation 10 means, in the driving mode the pump/motor assembly supplies supplementary power to the drive line using pressurised hydraulic fluid from the accumulation means, and in the neutral mode the pump/motor assembly is effectively inoperative and exerts no substantial driving or retarding influence on the drive line.

In one preferred embodiment, the reservoir includes a low-pressure 15 accumulator or constant pressure chamber adapted to supply a positive pressure to a suction port of the pump/motor unit, to minimise cavitation and facilitate the ingress of hydraulic fluid on demand.

In one implementation of this aspect of the invention, the drive line forms part of the drive train of a vehicle. Most preferably, the drive shaft of the pump/motor unit 20 is effectively integral with the drive line of the vehicle. In this case, the connection means can simply include a pair of universal joints allowing one sub-section of the drive line to be constituted by the drive shaft of the pump/motor unit, whereby the decoupling mechanism provides a releasable connection between the vehicle drive line and the cylinder block. In other embodiments, however, it will be appreciated 25 that gears, clutches, or other coupling mechanisms may be interposed to transmit rotary drive between the vehicle drive train and the pump/motor unit. Such transmission may be mechanical, hydraulic, pneumatic or electromagnetic. It may also be permanently engaged or decouplable, manual or automatic, and may include constant or variable reduction ratios.

30 Preferably, the pump/motor unit includes at least three external ports to permit ingress and egress of hydraulic fluid, with a first port communicating with an inlet of the hydraulic reservoir, a second port communicating with an outlet of the hydraulic

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reservoir, and a third port communicating with the accumulation means. A heat exchanger is preferably disposed between the first port and the hydraulic fluid reservoir.

In one embodiment of the invention, a plurality of positive displacement axial 5 piston pumps is arranged axially along the a common drive shaft. These pumps may be connected hydraulically to operate in series, parallel, or a combination of both.

Preferably, the energy management system includes a flow control circuit through which hydraulic fluid may be selectively directed, the control circuit being adapted to provide a controllable resistance enabling the pump/motor unit selectively 10 to exert a retarding force on the drive shaft when required, even if the accumulation means are fully charged.

Preferably, the accumulation means include a gas/liquid accumulator comprising a double-ended cylinder and a piston adapted to float sealingly within the cylinder. One side of the cylinder preferably contains a compressible inert gas such as 15 nitrogen, while the other side of the cylinder is preferably connected hydraulically to the pump/motor unit. The accumulator is preferably thereby adapted to store energy by pumping hydraulic fluid into one side of the cylinder, so as to compress the gas on the other side by displacement of the floating piston, and subsequently to release that energy by expulsion of hydraulic fluid as the compressed gas expands. In alternative 20 embodiments, however, other forms of accumulator, such as bladder, bellows or diaphragm type accumulators, may be readily substituted. The assembly optionally includes a plurality of accumulators, which may be selectively connected in series, parallel or a combination of both, as required.

25 BRIEF DESCRIPTION OF THE DRAWINGS

A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:-

figure 1 is a cross-sectional view showing a pump/motor assembly incorporating an integral decoupling mechanism including a clutch assembly 30 according to the invention;

figure 2 is an enlarged perspective view showing the drive shaft and selected components of the clutch from the pump/motor assembly of figure 1;

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figure 3 is a cross-sectional view of the shaft and surrounding clutch components of figure 2;

figure 4 is a partially exploded perspective view of a clutch pack from the clutch assembly according to the invention;

5 figure 5 is a side elevation showing the clutch pack of figure 4 in the assembled configuration;

figures 6 and 7 are perspective views, respectively showing individual inner and outer clutch plates from the clutch pack;

10 figure 8 is a side elevation showing the drive shaft from the pump/motor unit in isolation;

figure 9 is a cutaway perspective view showing the cylinder block from the pump/motor unit;

figure 10 is an enlarged sectional view showing the principal components of the clutch assembly from figure 2;

15 figure 11 is a perspective view of the piston assembly from figure 2;

figure 12 is a cross-sectional view of the piston assembly shown in figure 11;

figure 13 is an exploded perspective view of the piston assembly shown in figures 11 and 12;

20 figure 14 is a cross-sectional view of the decoupling mechanism with representation of the primary forces acting in the activation mode;

figure 15 is a cross-sectional view of the decoupling mechanism similar to figure 14, but showing the primary forces acting in the deactivation mode;

figure 16 is a cross-sectional view of the decoupling mechanism similar to figures 14 and 15, showing the primary forces acting in the preload mode;

25 figure 17 is a diagrammatic perspective view showing the pump/motor assembly of figures 1 to 16, incorporated into a road vehicle as part of a regenerative drive system (RDS), according to a further aspect of the invention.

PREFERRED EMBODIMENT OF THE INVENTION

30 Referring initially to figure 1, the invention provides a positive displacement hydraulic pump/motor unit 1. The pump/motor unit includes a stationary housing 2 and a cylinder block 3 supported within the housing for rotation about a central axis 5.

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The block 3 incorporates a circular array of hydraulic cylinders 6 uniformly disposed in parallel relationship about the central rotational axis 5. A corresponding array of axial pistons 10 is reciprocably disposed within the respective cylinders.

5 A central drive shaft 12 extends through a complementary bore 13 formed in the cylinder block. The shaft is connected to the cylinder block 3 by selectively releasable decoupling means 14, engageable to effect rotation of the block about the central axis, as described in more detail below.

10 A stationary drive plate in the form of swash plate 15 is disposed at one end of the cylinder block (the right-hand end when viewing the drawing). The swash plate is pivotably supported within the housing, for adjustable movement within a predetermined range, about an axis substantially normal to the rotational axis of the cylinder block.

15 A hold-down plate 16 is disposed to locate the free ends of the pistons remote from the valve plate in the appropriate relative spatial relationship, while the end faces of the pistons are formed with followers 18 adapted to engage and slidably traverse the operative surface of the swash plate. In this way, rotation of the cylinder block effects sequentially staggered reciprocation of the pistons, with the amplitude of piston travel being determined by the selected angle of inclination of the swash plate.

20 A stationary valve plate 20 is disposed at the opposite end of the cylinder block (the left-hand end when viewing the drawings) and is rigidly connected to the housing. The valve plate includes a valve face 21 adapted for sliding rotational engagement with a complementary mating valve face 22 formed on the abutting end of the cylinder block. The valve plate includes inlet ports 24 adapted for communication with a source of hydraulic fluid, and outlet ports 26 adapted for fluid 25 communication with a hydraulic load.

25 The valving is arranged such that hydraulic fluid is progressively drawn into the cylinders in sequence through the inlet ports as the pistons withdraw away from the valve plate and is subsequently expelled from the cylinders through the outlet ports as the respective pistons are progressively advanced toward the valve plate, 30 under the influence of the swash plate.

The swash plate is pivotably supported within the housing such that the effective angle of inclination with respect to the rotational axis of the cylinder block is

adjustable to provide selectively variable flow characteristics. In particular, the swash plate may be alternately inclined in a positive and a negative sense, thereby enabling the assembly selectively to operate as a motor or a pump. In this regard, it should be appreciated that the particular valve ports which function as inlets to the cylinders of 5 the pump/motor unit, and those which function as outlets, will alternate according to the operational mode of the unit. Importantly, the swash plate can also be orientated in an intermediate or neutral position in a plane effectively normal to the central axis, such that rotation of the cylinder block produces no reciprocation of the pistons. In this mode, the pump/motor unit induces no net fluid flow into or out of the cylinders, 10 and consequently transfers no significant hydraulic load to the shaft.

The essential elements of construction and the basic principles of operation are common to most positive displacement axial piston hydraulic pumps, and being well understood by those skilled in the art, need not be described in more detail.

The decoupling mechanism 14 includes a multiple plate clutch assembly 29, 15 which acts between the inner drive shaft 12, and the surrounding cylinder block 3. The clutch assembly includes a clutch pack 30 and an associated piston assembly 31. The clutch pack 30 includes a stack of inner clutch plates 32 and complementary outer clutch plates 34 in alternating order. Each clutch plate includes a central aperture for receiving the shaft 12, so that the stack is disposed coaxially around the shaft and the 20 clutch assembly is integrally formed within the pump/motor housing.

As best seen in figures 4 to 9, each inner clutch plate 32 includes frictional engagement surfaces 36 on opposing sides of the plate and a ring of teeth 38 around the periphery of the aperture. These teeth are adapted for engagement with complementary spline formations 42 on the shaft. Similarly, each outer clutch plate 25 34 includes respective frictional engagement surfaces 44 on opposing sides of the plate and an outer peripheral ring of teeth 46. These teeth engage complementary splines 48 formed on the cylinder block, as best shown in figure 9.

In this way, the inner and outer clutch plates are splined to the shaft and cylinder block respectively. The splined engagement provides for a limited degree of 30 axial displacement of the inner and outer plates, while preventing rotational displacement between the clutch plates and the respective components to which they

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are splined. In this embodiment, the clutch is a wet type clutch, in the sense that the entire clutch pack is immersed in hydraulic fluid.

At the forward end (the right hand end in the drawings) the stack is bounded by clutch pack plate 50, clutch pack shim 52 and clutch pack front plate 54, as best seen in figures 4, 5 and 10. The clutch pack plate 50 includes a ring of teeth around a central aperture and is splined to the shaft in the same way as the inner clutch plates. Accordingly, the clutch pack plate, clutch pack shim and clutch pack front plate all rotate with the shaft. The front plate 54 is keyed to the shaft 12 via end stop 56. In this way, axial forces applied through the clutch pack are transferred to the shaft. At 10 the other end of the clutch stack, a rear clutch plate 58 distributes axial loading to the stack. The rear clutch plate is also splined to the shaft by a ring of teeth disposed around the periphery of a central aperture. The front and rear clutch plates and the clutch pack plate are designed to be more resistant to bending and are typically thicker than the plates in the stack. This provides for an even distribution of axial load 15 throughout the stack.

In normal operation, axial activation pressure is applied through the rear clutch plate to the stack. This causes the mating surfaces on the respective inner and outer plates to frictionally engage, so that torque may be transmitted between the shaft and the cylinder block. By releasing the axial pressure from the stack, the inner and outer 20 plates, splined to the shaft and cylinder block respectively, are able to rotate at different angular velocities. Moreover, by varying the amount of axial pressure applied to the stack, it is possible to selectively and progressively vary the amount of torque transmitted between the shaft and cylinder block via the clutch plates. It is also possible to controllably regulate the speed transmission or slippage ratio.

25 To provide the activation pressure, the decoupling mechanism utilises a hydraulic piston assembly 60, also disposed coaxially around the main drive shaft 12. Referring to figures 10 to 15, the piston assembly 60 includes valve plate 62 and piston case 64 which houses activation piston 66 and release piston 68. The release piston is retained with the activation piston by a stop ring 70. When assembled, the 30 piston case, activation piston and release piston combine to form an activation chamber 72 and a release chamber 74. Each chamber is substantially sealed by a combination of sealing rings 76, 78 and 80.

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In the activation or engaged mode, as indicated by the arrows in figure 14, pressurising the activation chamber 72 has the effect of urging the activation piston forward, thereby compressing the clutch pack and activating or engaging the clutch. As previously noted, this activation force is transferred through the clutch pack and 5 front plate 54 to the shaft 12.

In this mode of operation, the reactive force is transmitted through the piston case 64 to the shaft via rear thrust bearing 82 and respective fore and aft rear thrust bearing runners, 84 and 86. A shoulder 88 on the shaft abuts the aft bearing runner 86 to distribute the axial forces from the clutch assembly to the rearward end of the shaft. 10 In this way, the axial compressive forces generated by the clutch are borne by the shaft at the rear of the piston assembly through the aft thrust bearing runner 86, and at the front of the clutch pack via the front plate 54. Advantageously, this shaft-to-shaft reaction isolates the axial loads from the shaft end bearings.

Conversely, in deactivation or disengaged mode, shown in figure 15, 15 pressurisation of the release chamber 74 urges the release piston and activation piston away from the clutch pack, thereby deactivating or disengaging the clutch. The piston case is configured to allow for a small amount of axial movement relative to the cylinder block and the shaft to limit the reactive force that is transmitted from the piston case to the valve plate. This ensures that any frictional forces generated during 20 deactivation of the clutch are not transferred to the shaft end bearings.

It will be appreciated that the piston assembly does not rotate with either the shaft or the cylinder block. Advantageously, this enables straightforward routing of hydraulic fluid supply lines (not shown) from the stationary valve plate to the pressure chambers 72 and 74. The piston case, activation piston, release piston and thrust 25 bearing runner 86 are sandwiched by the rear thrust bearing 82 at the rearward end and by the front thrust bearing 90 at the other end. Consequently, there is no direct contact between the activation piston and the shaft.

From the foregoing description it will be apparent that the clutch is both positively activated and positively deactivated by hydraulic pressure. In normal 30 operation, this pressure is generated by the pump/motor unit or supplied from hydraulic accumulators (as outlined in more detail below). In the event that the clutch is deactivated and there is insufficient residual pressure in the accumulators, a bevel

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spring 94 provides a minimal preload force to the activation piston, sufficient to effect partial activation or engagement of the clutch. This allows enough torque to be transferred to the cylinder block to operate the pump and thereby pressurise the system. Once the system is pressurised, the clutch can be fully activated in the usual 5 manner. Typically, the bevel spring applies a preload to the piston of 1/30 of the force required to produce full torque transmission through the clutch. When in deactivation or disengaged mode, it will be apparent that the pressurisation of the release chamber must be held to counter the preload of the bevel spring so that the clutch is fully disengaged.

10 In alternative forms, a supplementary charge pump, or pressurised hydraulic fluid diverted from the accumulators, may be used to generate a pilot pressure sufficient to partially engage the clutch. Advantageously, however, the preferred embodiment does not require these modifications, which would compromise the overall efficiency of the system to some degree.

15 It is envisaged that the decoupling mechanism may be embodied in various other forms. For example, the piston assembly may be replaced by a more conventional clutch spring. The wet multi-plate clutch may also be replaced by a dry type multi-plate clutch, viscous clutch, cone clutch or any other type of suitable clutch system. In still further forms, the decoupling mechanism may be used in conjunction 20 with, or replaced by torque converters, viscous couplings or variable fluid drives.

25 The present invention in its various forms as illustrated is particularly well adapted for implementation as part of a regenerative drive system (RDS) of the type previously described by the present applicant in the earlier application No. PCT/AU99/00740. An example of one such implementation in a vehicle chassis 70 is illustrated in figure 17.

Referring to figure 17, the hydraulic pump/motor assembly 1, as described above, forms part of an energy management system 102, wherein the drive shaft 12 of the pump/motor unit is connected to the drive line or power train of the vehicle via yokes 104 and 106. In situ, these yokes form parts of universal joints at the respective 30 ends of the drive shaft. In this way, the drive shaft of the pump/motor unit becomes serially connected with, and an integral part of, the drive line of the vehicle, thereby obviating the need for gearboxes, chain drives, belt drives, or other intermediate

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transmission mechanisms. This makes the unit efficient, compact, reliable, and readily retrofittable to existing vehicles.

In this implementation, the system further includes energy accumulation means in the form of a pair of gas/liquid accumulators 108, each comprising a double-ended cylinder and a piston (not shown) adapted sealingly to float within the cylinder. 5 One side of each cylinder contains a compressible inert gas such as nitrogen, while the other side of the cylinder is in fluid communication with the pump/motor unit and hydraulic reservoir 110 via respective hydraulic lines. Each accumulator is thereby adapted to store energy by receiving pressurised hydraulic fluid into one side of the cylinder so as to compress the gas on the other side, and adapted subsequently to release that energy by expulsion of the hydraulic fluid as the compressed gas is allowed to expand. This method of energy accumulation and regeneration is well understood by those skilled in the art, and is described in more detail in PCT/AU99/00740. Again, however, it should be emphasised that alternative forms of 15 energy accumulator such as bladder, bellows or diaphragm type accumulators can readily be substituted and further, that any suitable number of accumulators may be used.

In use, the system is selectively operable in any one of three primary modes. 20 In a first braking mode, the system operates to retard the drive shaft of the vehicle by pumping hydraulic fluid into the accumulators and thereby compressing the contained gas medium. Alternately, the system is operable in a driving mode to supply supplementary power to the drive shaft of the vehicle using the pressurised hydraulic fluid from the accumulators. In the braking mode, it will be appreciated that the hydraulic pump/motor unit operates as a pump powered by the vehicle drive shaft, 25 whereas in the driving mode, the unit operates as a motor powered by pressurised hydraulic fluid from the accumulators. The system is also operable in a third neutral or "free wheeling" mode, whereby the drive shaft of the vehicle is substantially unaffected by the pump/motor unit, aside from any residual frictional drag which the present invention aims to minimise.

30 In this regard, in the neutral or free-wheeling mode, the decoupling mechanism can be used to selectively disengage the drive shaft from the motor/pump unit. As previously described, this avoids the need for the cylinder block to rotate in unison

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with the drive shaft when not required. The effect of this disengagement is to substantially eliminate a primary source of hydrodynamic drag, which otherwise arises by virtue of the fact that the rotational group spins in an oil bath contained within the housing. Decoupling of the cylinder block from the drive shaft also 5 effectively eliminates frictional drag at the sliding interface between the cylinder block and the valve plate. Advantageously, this combined reduction in internal friction and drag significantly reduces the parasitic losses of the system in the free-wheeling mode.

The clutch system for decoupling also advantageously allows for progressive 10 disengagement, which can be controlled to facilitate smoother transitions between the engaged and disengaged modes of operation. This renders the activation and deactivation of the system less intrusive from the operator's perspective, and makes the hardware less susceptible to failure, wear and fatigue as a result of transient shock loads.

15 The decoupling mechanism also allows the shaft to spin to a higher angular velocity than the cylinder block through controlled slippage. This is significant because in vehicular applications, the pump/motor unit will typically have a lower maximum safe angular velocity than that of the shaft due to its relatively higher rotational inertia. By way of example, the pump/motor unit will typically have a 20 rotational speed limit in the range of 1500 to 2200 rpm (subject to the size and configuration of the unit, the materials employed, manufacturing tolerances and other factors) while the maximum shaft speed in a typical heavy vehicular application may be as high as 3500 rpm. When these two components are coupled for conjoined 25 rotation, the maximum safe rotational speed of the pump/motor unit becomes the rate-limiting factor in terms of shaft speed. By decoupling the shaft from the pump/motor unit and allowing a degree of controlled slippage through the clutch, the maximum rotational speed of the shaft may be increased relative to the pump, while a predetermined proportion of working torque continues to be transferred. Significantly, this can be achieved without the additional cost, complexity, weight and 30 bulk of an intermediate gearbox or other transmission system.

The three primary operational modes are controlled by the angle of inclination of the swash plate 15, in the manner previously described. This angle, together with

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the operation of the decoupling mechanism, is regulated by a computerised RDS controller 100. The RDS controller is programmably responsive to a predetermined series of system parameters such as accelerator, brake and clutch pedal positions, engine speed, gear selection, engine manifold pressure, swash plate position, drive 5 line torque, accumulator pressure and hydraulic pump/motor pressure. The system may also be pre-programmed with topographical mapping and terrain data, thereby enabling it effectively to anticipate inclines and declines as well as stopping and acceleration points on known routes, and optimise the performance of the RDS on that basis.

10 The pump/motor assembly of the RDS as illustrated is positioned in the central drive line of the vehicle, immediately downstream of the engine 112 and gearbox 114. This is advantageous, because in that position, the system can be readily retrofitted to existing vehicles by replacement of a standard section of the original drive line. It should be understood, however, that the unit may alternatively be positioned between 15 the engine and gearbox, for example in direct connection with the crank shaft. It may also be positioned downstream of one or both of the differentials 116, and may even be incorporated into an axle. In that case, it will be apparent that several pump/motor units may be incorporated into multiple drive line sections, axles or stub axles.

While the particular implementation of the invention shown in the drawings is 20 described predominantly in the context of heavy road going vehicles, it will also be appreciated that regenerative drive systems of this type can be readily adapted to practically any environment in which it is advantageous to store excess mechanical energy at some time, for use at a later time. Typical examples of other potential applications include elevators and lifts, escalators and travelators, conveyors, cranes 25 and other lifting devices, as well as other forms of transportation such as rail, shipping and aeronautical applications.

The present invention provides an efficient and effective mechanism for reducing frictional or hydrodynamic drag under off-load conditions in hydraulic pumps and motors, of almost any configuration and in virtually any application 30 including vane, gear and radial piston pumps. Moreover, this can be achieved without compromising sealing performance under heavy load or high pressure conditions. The benefits of this are particularly substantial in the context of regenerative drive

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systems, wherein the pump/motor unit may be required to operate in a neutral or freewheeling mode for prolonged periods, and any residual frictional drag and parasitic losses during such periods can consequently impact materially on the overall efficiency of the system. In these respects, the invention represents both a practical
5 and a commercially significant improvement over the prior art.

Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that the invention may be embodied in many other forms.

CLAIMS

1. A positive displacement hydraulic pump/motor assembly including:
 - a rotary cylinder block having a central axis and incorporating a generally circular array of cylinders disposed around the axis;
 - 5 a corresponding plurality of pistons reciprocably disposed within the respective cylinders;
 - drive means including a drive shaft extending through a bore formed in the cylinder block to effect rotation of the cylinder block about the central axis;
 - 10 a drive plate disposed at one end of the cylinder block to effect sequentially staggered reciprocation of the pistons in response to rotation of the cylinder block;
 - 15 a stationary valve plate disposed at an opposite end of the cylinder block, the valve plate having a valve face adapted for sliding rotational engagement with a complementary mating face formed on the cylinder block;
 - the valve plate further including at least one inlet port for fluid communication
 - 20 with a source of hydraulic fluid and at least one outlet port for fluid communication with an hydraulic load;
 - the ports being disposed such that in use, hydraulic fluid is progressively drawn into the cylinders in sequence as the respective pistons are displaced away from the valve plate and subsequently expelled from the cylinders as the pistons are progressively displaced toward the valve plate;
 - the pump/motor assembly further including a selectively releasable decoupling mechanism adapted in an engaged mode to connect the drive shaft to the cylinder block and in a disengaged mode to allow the drive shaft to rotate substantially independently of the cylinder block.
- 25 2. A pump/motor assembly according to claim 1, wherein the cylinders are disposed in generally parallel relationship with respect to the central axis.
3. A pump/motor assembly according to claim 1 or claim 2, wherein the drive plate takes the form of a stationary swash plate, which is inclined with respect to the central axis of the cylinder block.
- 30 4. A pump/motor assembly according to claim 3, wherein floating ends of the pistons remote from the valve plate include followers adapted to traverse the swash plate as the cylinder block rotates.

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5. A pump/motor assembly according to claim 4, further including a hold-down plate disposed to capture the floating ends of the pistons and retain the followers in sliding contact with the swash plate.
6. A pump/motor assembly according to any one of claims 3 to 5, wherein the 5 angle of inclination of the swash plate is selectively adjustable, to provide variable flow rate characteristics.
7. A pump/motor assembly according to claim 6, wherein the swash plate is able to be selectively inclined in a positive or a negative sense, thereby enabling the assembly alternately to operate as a motor or a pump.
- 10 8. A pump/motor assembly according to claim 6 or claim 7, wherein the variable swash plate can be oriented in an intermediate or neutral position, effectively normal to the central axis, such that rotation of the cylinder block causes no movement of the pistons, and hence induces no substantial load.
- 15 9. A pump/motor assembly according to any one of the preceding claims, further including bias means disposed to apply a bias force urging the respective mating faces on the cylinder block and the valve plate into sealing engagement.
10. A pump/motor assembly according to claim 9, wherein the bias force applied by the bias means is selectively variable.
11. A pump/motor assembly according to any one of the preceding claims, 20 wherein the decoupling means include a clutch mechanism interposed effectively between the drive shaft and the cylinder block, so as selectively to transmit rotary drive therebetween.
12. A pump/motor assembly according to claim 11, wherein the clutch mechanism includes a multi-plate clutch disposed coaxially around the drive shaft.
- 25 13. A pump/motor assembly according to claim 12, wherein the clutch mechanism includes a stack of inter-leaved inner and outer clutch plates, configured for splined engagement with the drive shaft and cylinder block respectively.
14. A pump/motor assembly according to claim 13, wherein the clutch plates are disposed such that compression of the clutch stack upon engagement of the clutch 30 promotes frictional engagement between the inner and outer clutch plates, thereby to transmit torque between the shaft and cylinder block.

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15. A pump/motor assembly according to claim 14, wherein the clutch mechanism includes a piston assembly configured selectively to compress the plates in the clutch stack in order to engage the clutch.
16. A pump/motor assembly according to claim 15, wherein the piston assembly is 5 non-rotating.
17. A pump/motor assembly according to claim 15 or claim 16, wherein the piston assembly is configured such that activation and reaction forces are transferred to the drive shaft, thereby substantially isolating clutch-induced compressive loads from shaft end bearings.
- 10 18. A pump/motor assembly according to any one of claims 11 to 17, wherein the clutch mechanism is selectively capable of substantially complete disengagement, so as to provide for substantially independent rotation of the shaft and the cylinder block.
19. A pump/motor assembly according to any one of claims 11 to 18, wherein the clutch mechanism is capable of partial disengagement, so as to transmit a proportion 15 of torque between the shaft and cylinder block.
20. A pump/motor assembly according to any one of claims 11 to 19, wherein the clutch mechanism is progressively and controllably actuatable between the engaged and disengaged modes of operation, to provide for controlled slippage.
21. A pump/motor assembly according to any one of claims 11 to 20, wherein the 20 clutch mechanism is positively engaged and positively disengaged by hydraulic pressure.
22. A pump/motor assembly according to claim 21, wherein the hydraulic pressure for engagement and disengagement of the clutch is provided by the pump/motor assembly.
- 25 23. A pump/motor assembly according to any one of claims 11 to 23, wherein the clutch mechanism is a wet type design, with the clutch plates submerged at least partially in an oil bath.
24. An energy management system operable in a driving mode, a braking mode and a neutral mode, the energy management system including:-
- 30 energy accumulation means operable selectively to store and release energy through controlled receipt and release of hydraulic fluid;

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a positive displacement hydraulic pump/motor assembly as defined in any one of the preceding claims, in fluid communication with the energy accumulation means;

a low pressure hydraulic reservoir in fluid communication with the pump/motor assembly; and

5 connection means for connecting the pump/motor assembly to a drive line; the system being arranged such that in the braking mode the pump/motor assembly retards the drive line by pumping hydraulic fluid into the accumulation means, in the driving mode the pump/motor assembly supplies supplementary power to the drive line using pressurised hydraulic fluid from the accumulation means, and in 10 the neutral mode the pump/motor assembly is effectively inoperative and exerts no substantial driving or retarding influence on the drive line.

25. An energy management system according to claim 24, wherein the reservoir includes a low-pressure accumulator or constant pressure chamber adapted to supply a positive pressure to a suction port of the pump/motor unit.

15. 26. An energy management system according to claim 24 or claim 25, wherein the drive line forms part of a drive train of a vehicle.

27. An energy management system according to claim 26, wherein the drive shaft of the pump/motor assembly is effectively integral with the drive line of the vehicle.

28. An energy management system according to claim 27, wherein the connection 20 means include a pair of universal joints allowing one sub-section of the drive line to be constituted by the drive shaft of the pump/motor unit, such that the decoupling mechanism provides a releasable connection between the vehicle drive line and the cylinder block.

29. An energy management system according to claim 24, wherein the connection 25 means include an intermediate transmission mechanism disposed to transmit rotary drive between the vehicle drive train and the drive shaft of the pump/motor assembly.

30. An energy management system according to any one of claims 24 to 29, wherein the pump/motor assembly includes at least three external ports to permit ingress and egress of hydraulic fluid, with a first port communicating with an inlet of 30 the hydraulic reservoir, a second port communicating with an outlet of the hydraulic reservoir, and a third port communicating with the accumulation means.

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31. An energy management system according to claim 30, further including a heat exchanger disposed between the first port and the hydraulic fluid reservoir.
32. An energy management system according to claim 24, wherein a plurality of said pump/motor assemblies is arranged axially along a common drive shaft.
- 5 33. An energy management system according to any one of claims 24 to 32, further including a flow control circuit through which hydraulic fluid can be selectively directed, the control circuit providing a controllable resistance enabling the pump/motor assembly selectively to exert a retarding force on the drive shaft when the accumulation means are fully charged.
- 10 34. An energy management system according to according to any one of claims 24 to 33, wherein the accumulation means include a gas/liquid accumulator comprising a double-ended cylinder and a piston adapted to float sealingly within the cylinder, and wherein side of the cylinder contains a compressible inert gas and the other side of the cylinder is connected hydraulically to the pump/motor assembly.
- 15 35. An energy management system according to claim 34, wherein the accumulator is adapted to store energy by pumping hydraulic fluid into one side of the cylinder so as to compress the gas on the other side by displacement of the floating piston, and subsequently to release that energy by expulsion of hydraulic fluid as the compressed gas expands.
- 20 36. An energy management system according to claim 35, including a plurality of said accumulators, connected in series or parallel.

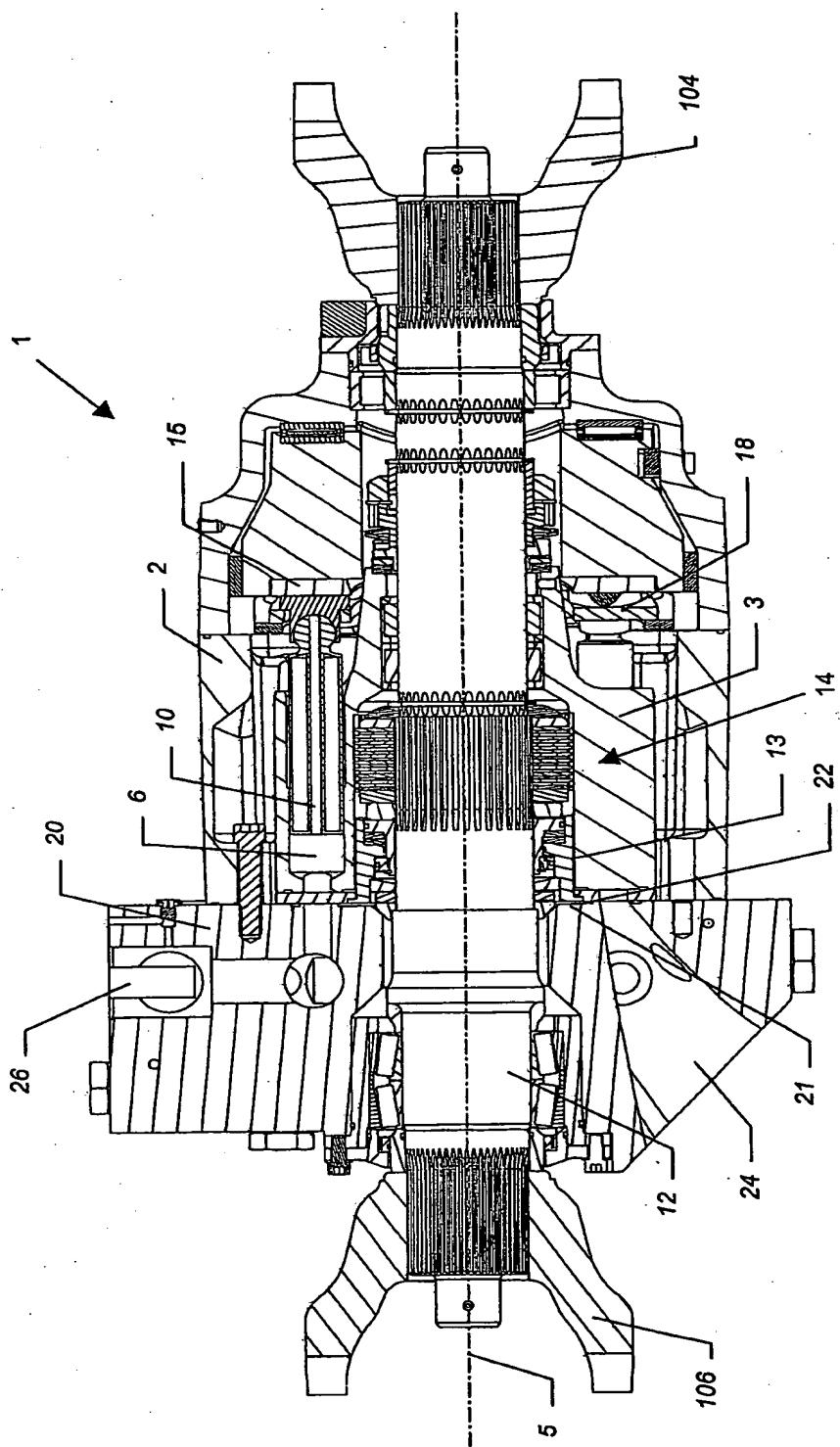
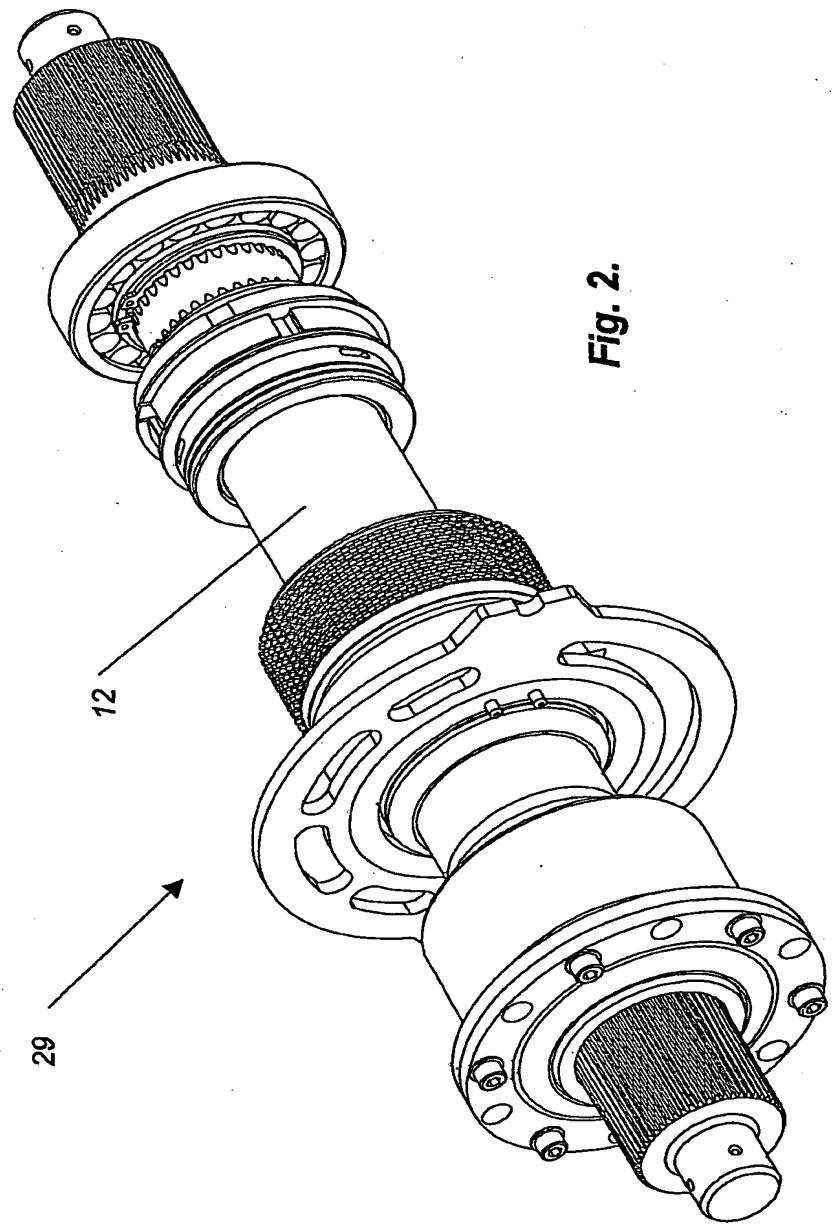


Fig. 1.



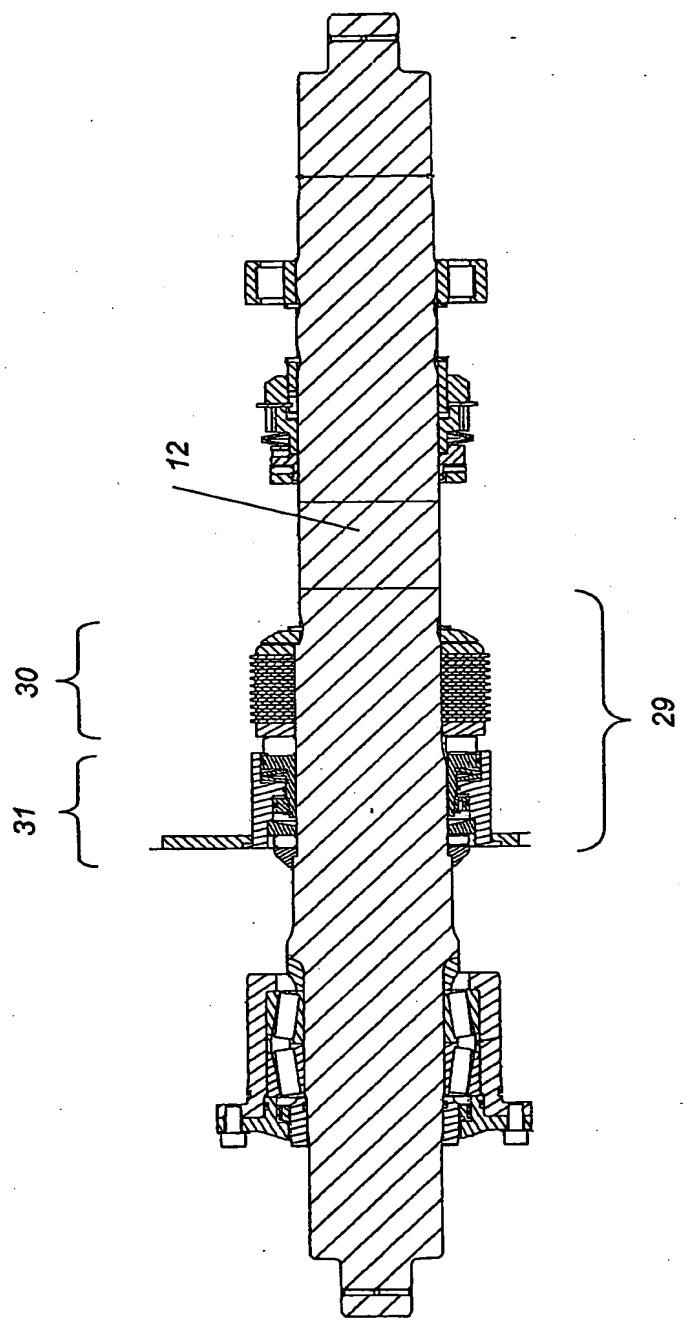


Fig. 3.

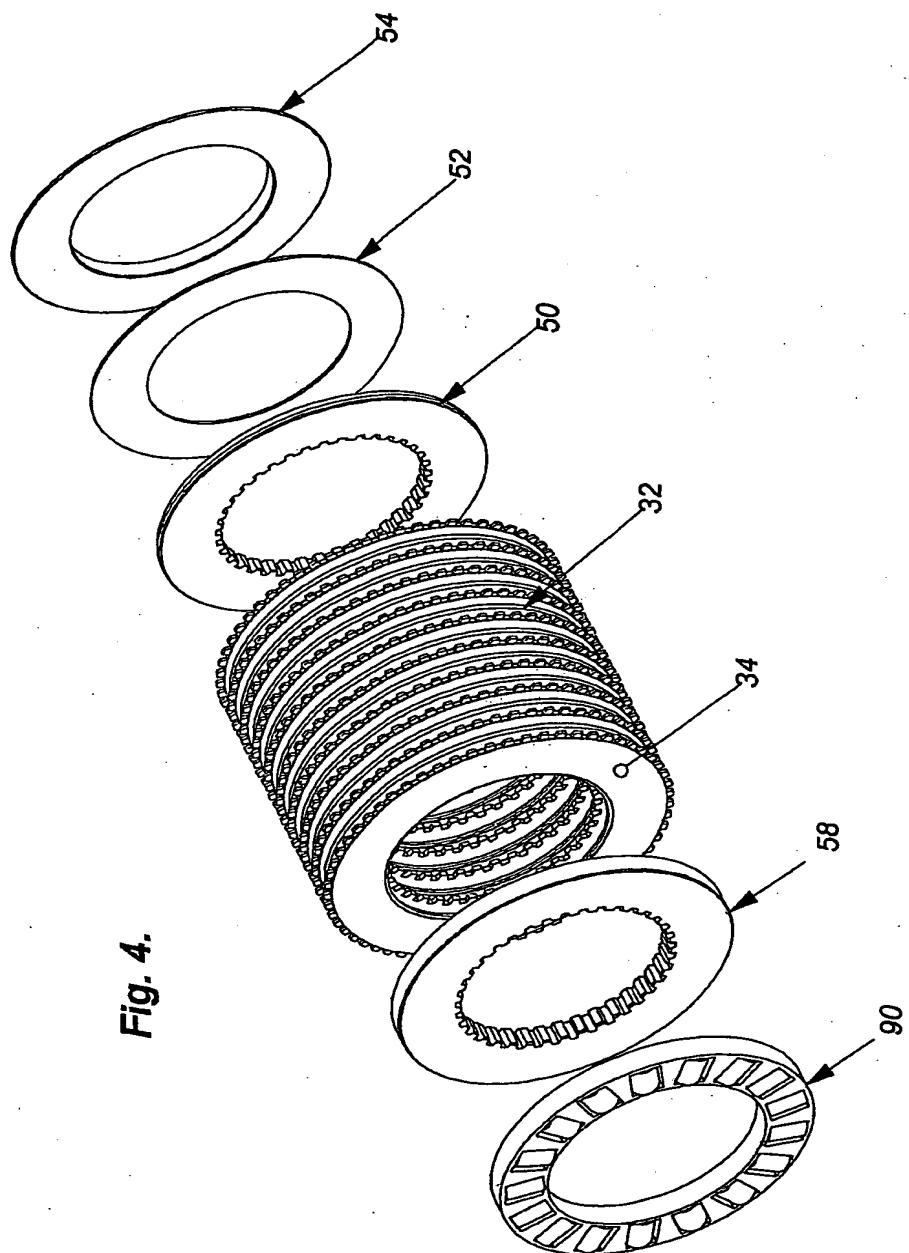
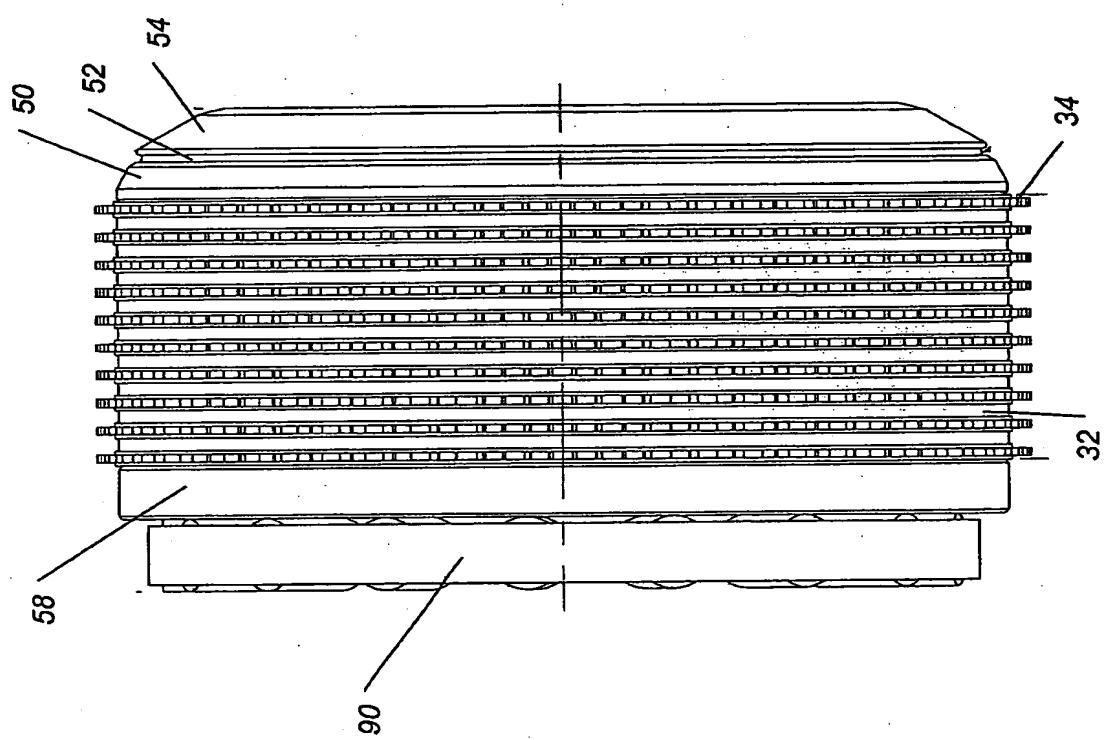


Fig. 5.



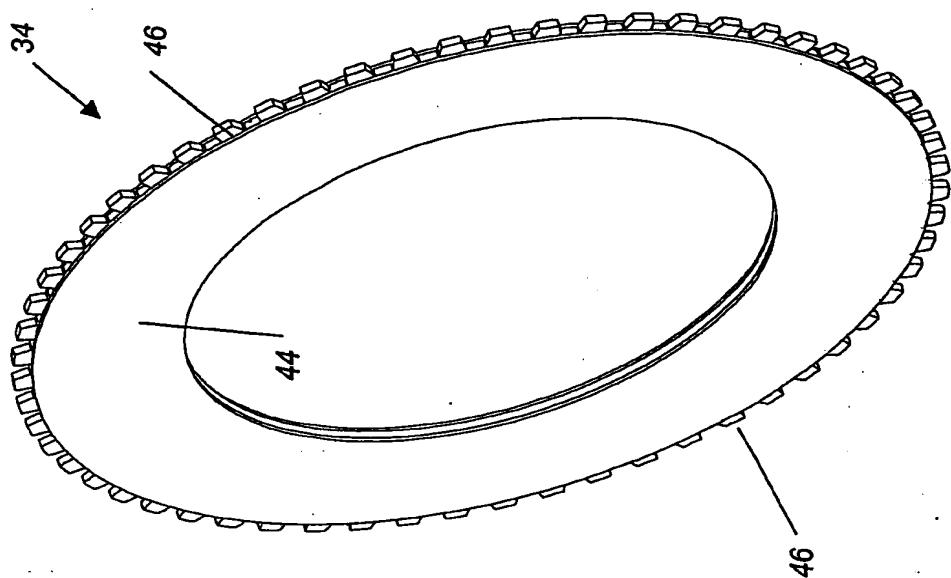


Fig. 7.

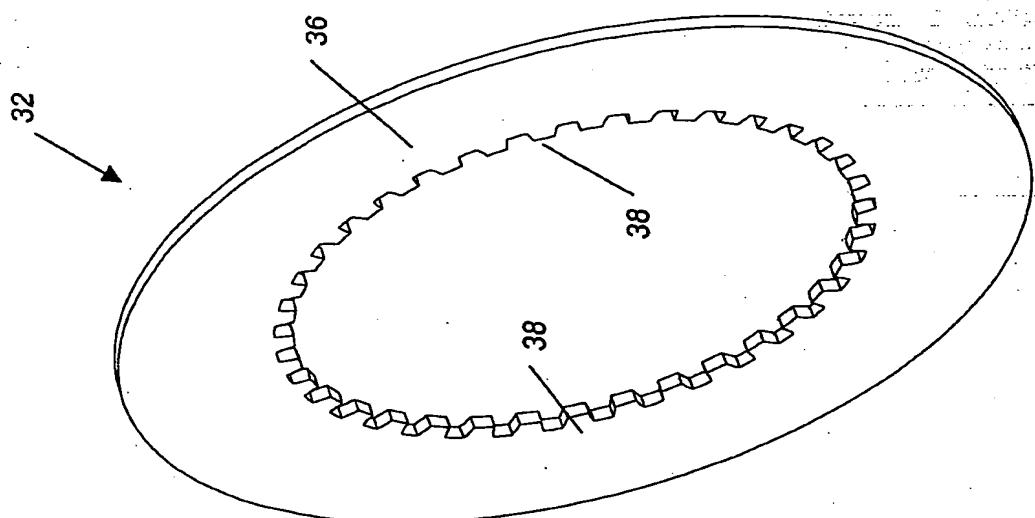
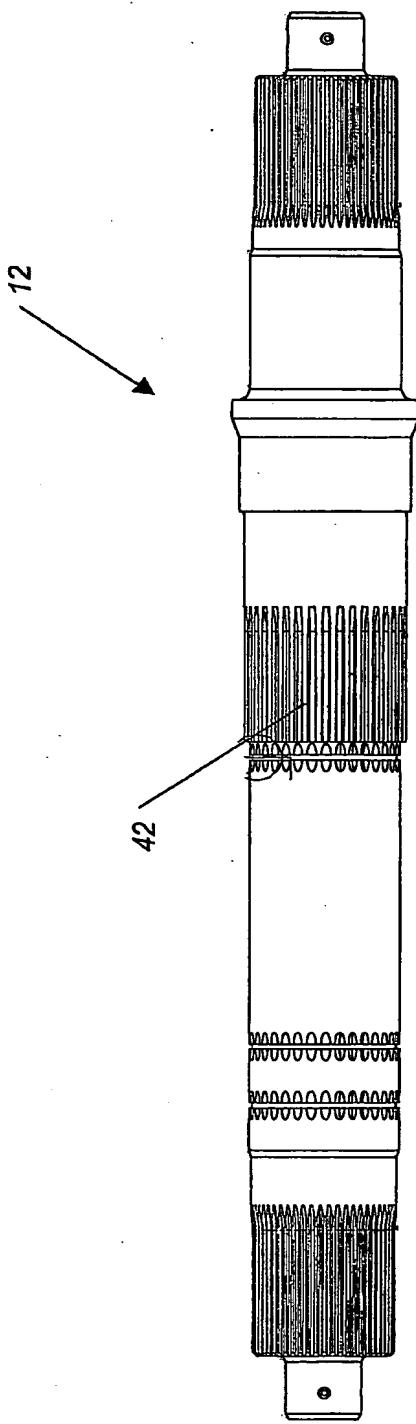


Fig. 6.

Fig. 8.



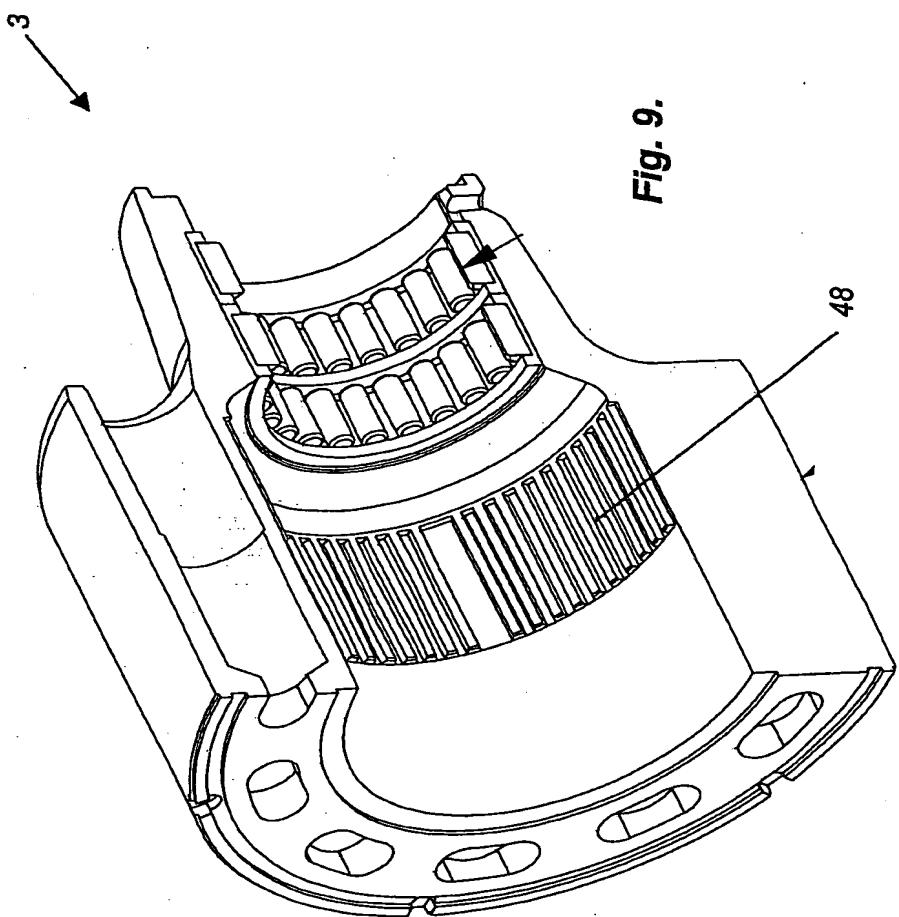
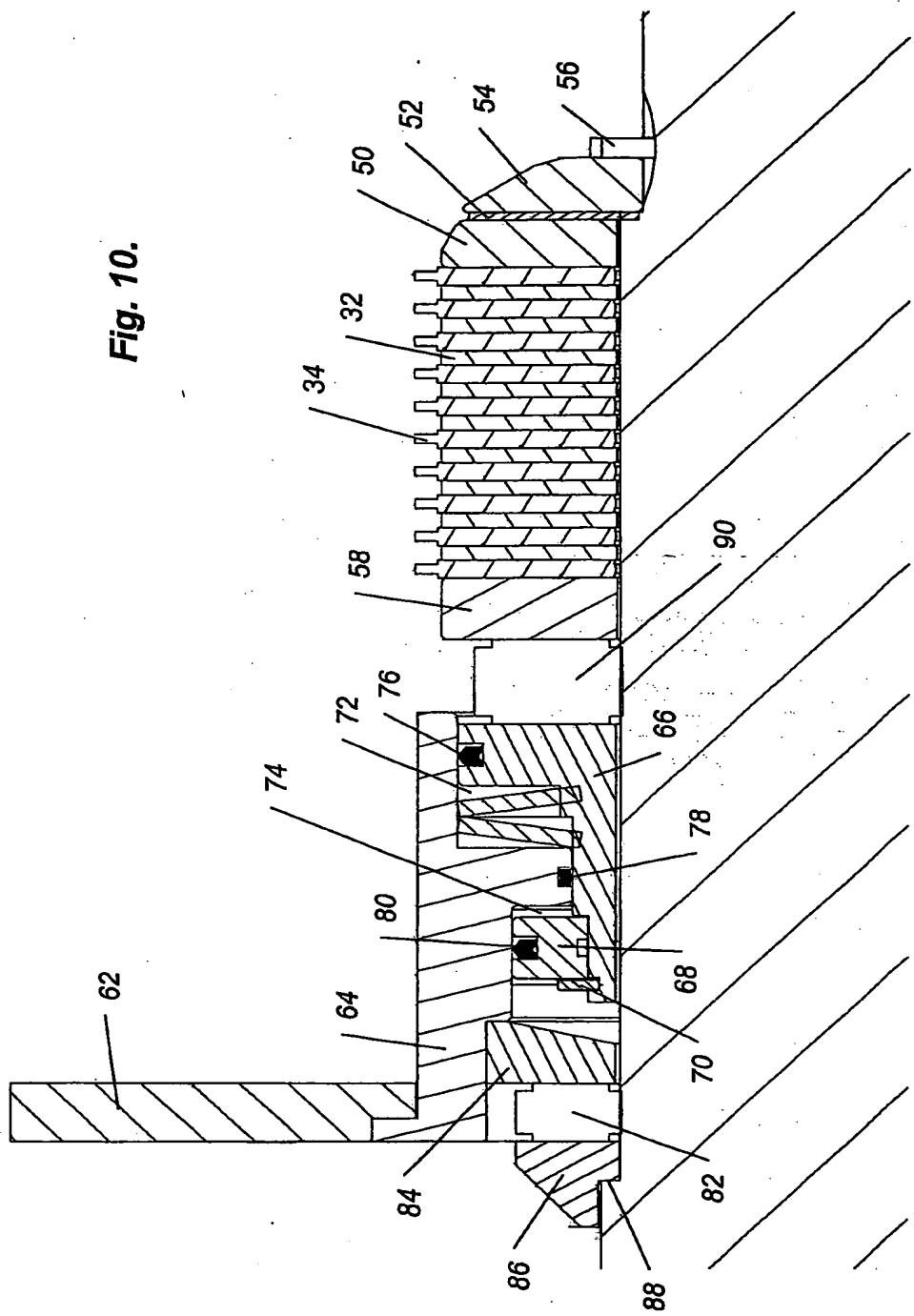


Fig. 10.



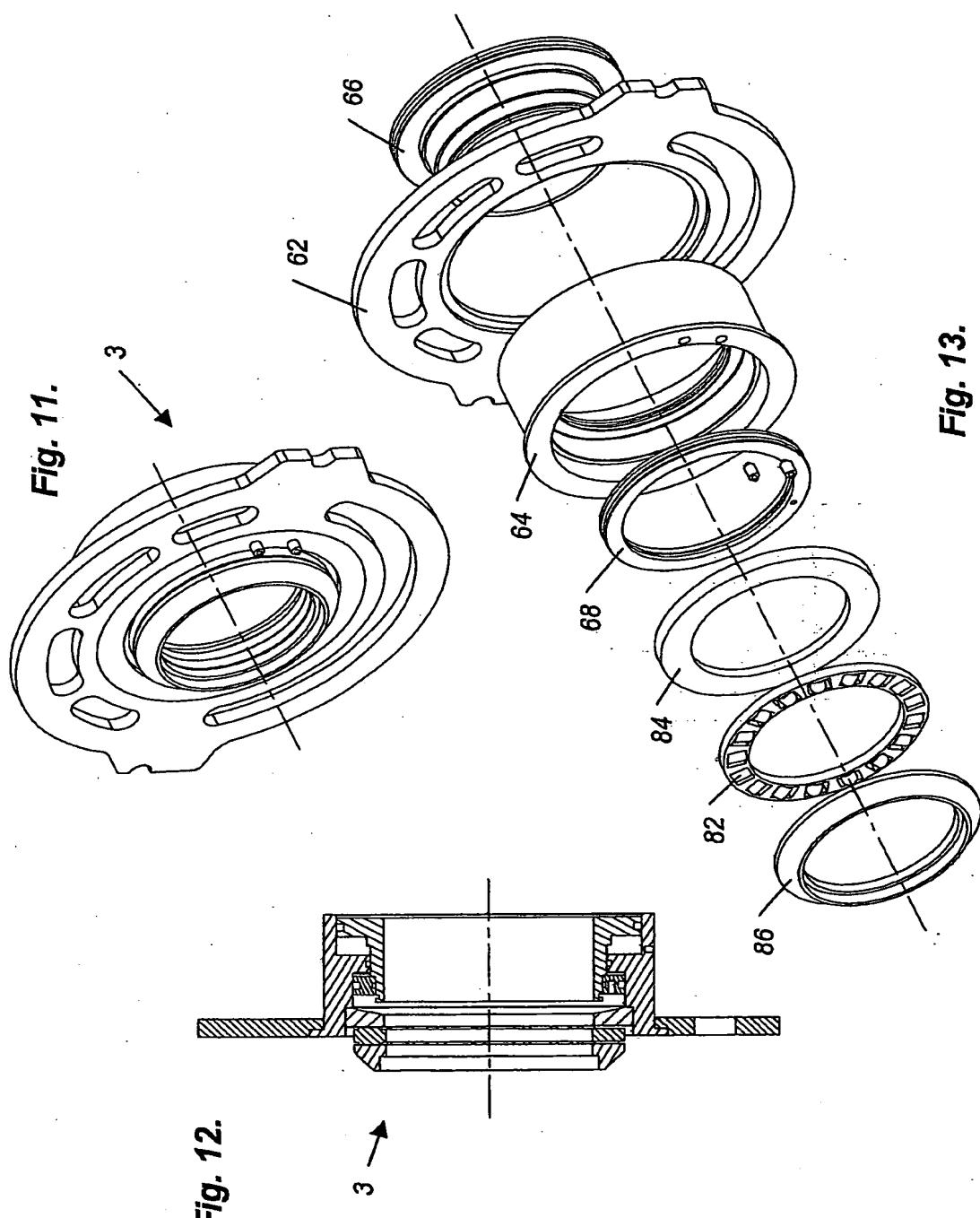


Fig. 14.

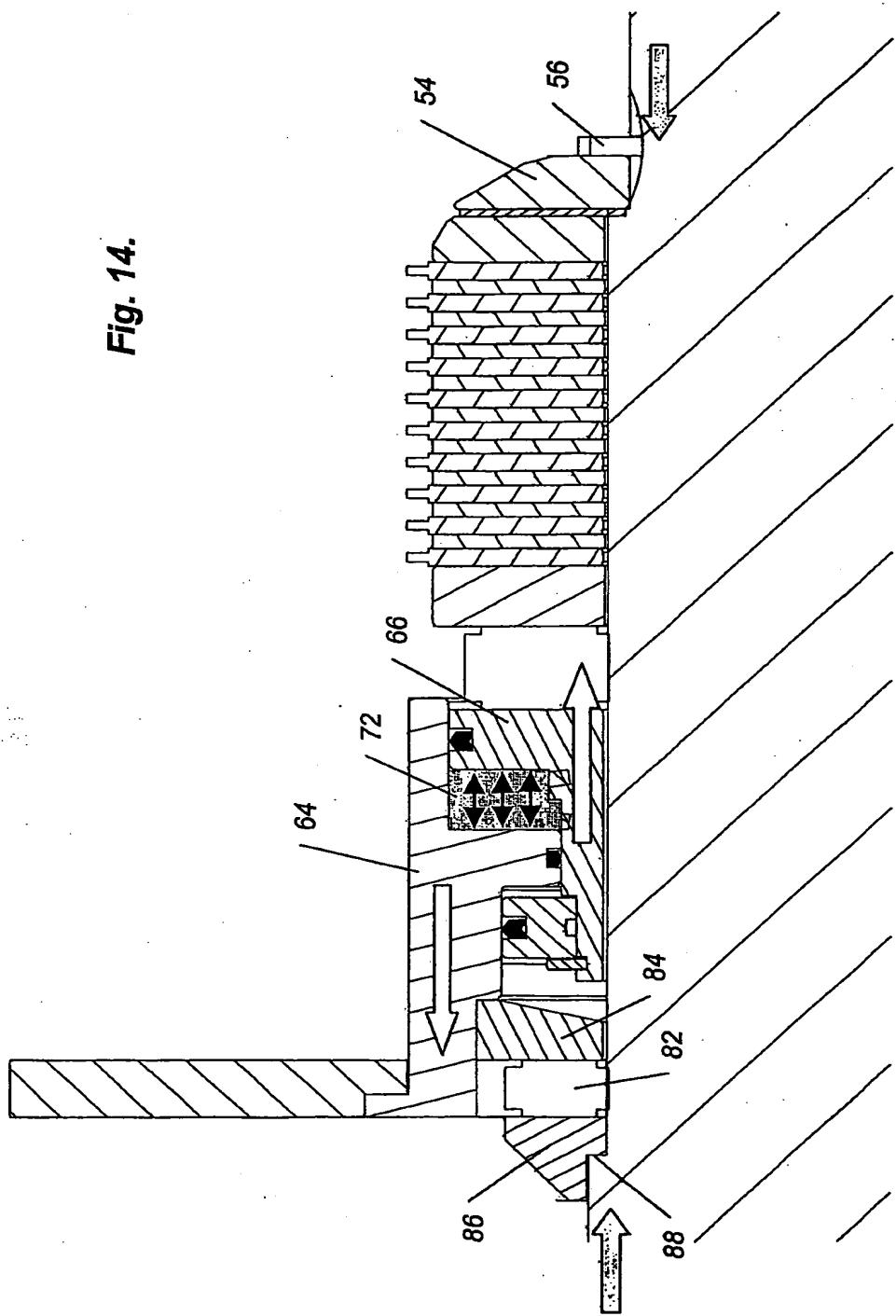


Fig. 15.

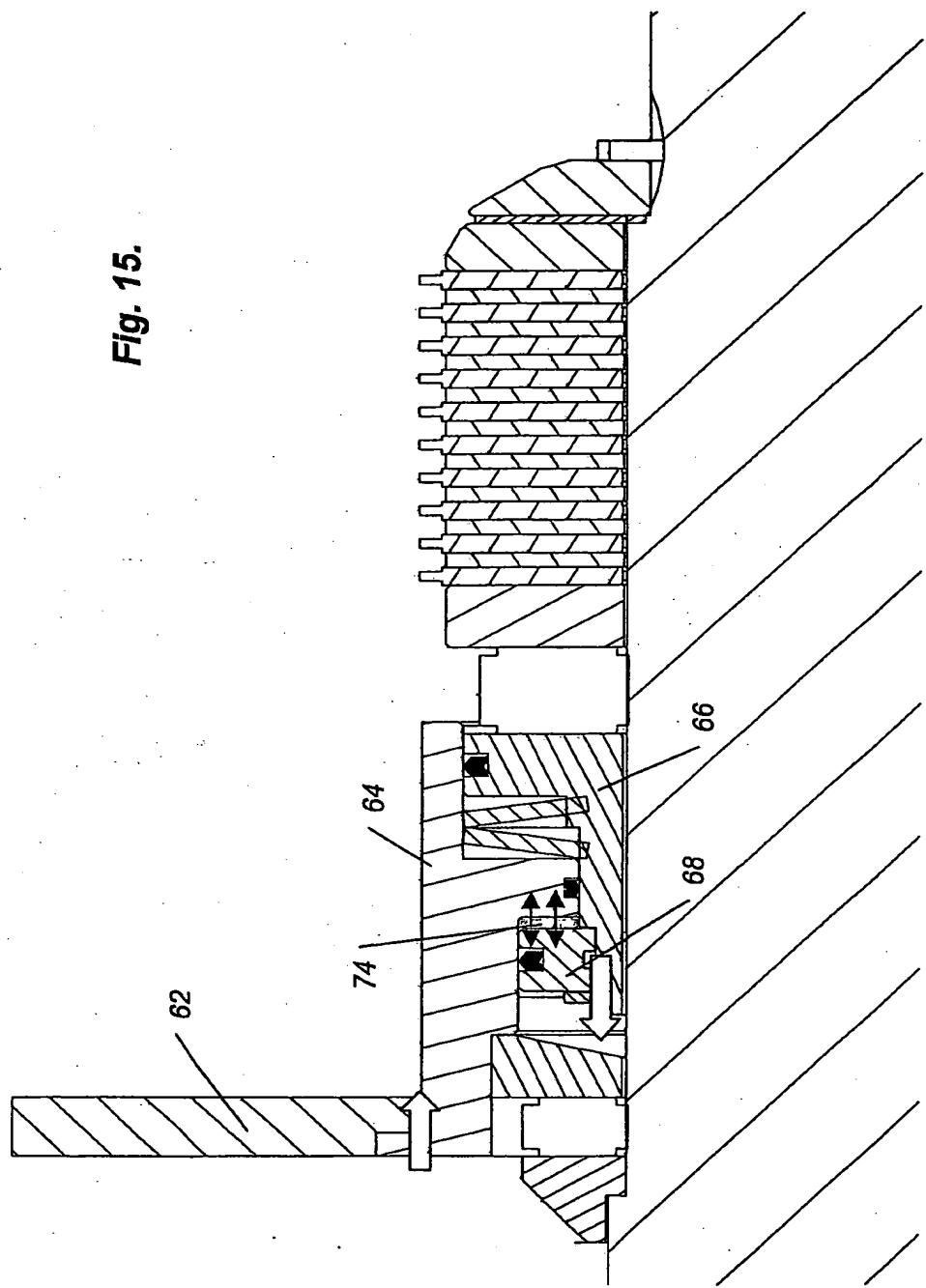
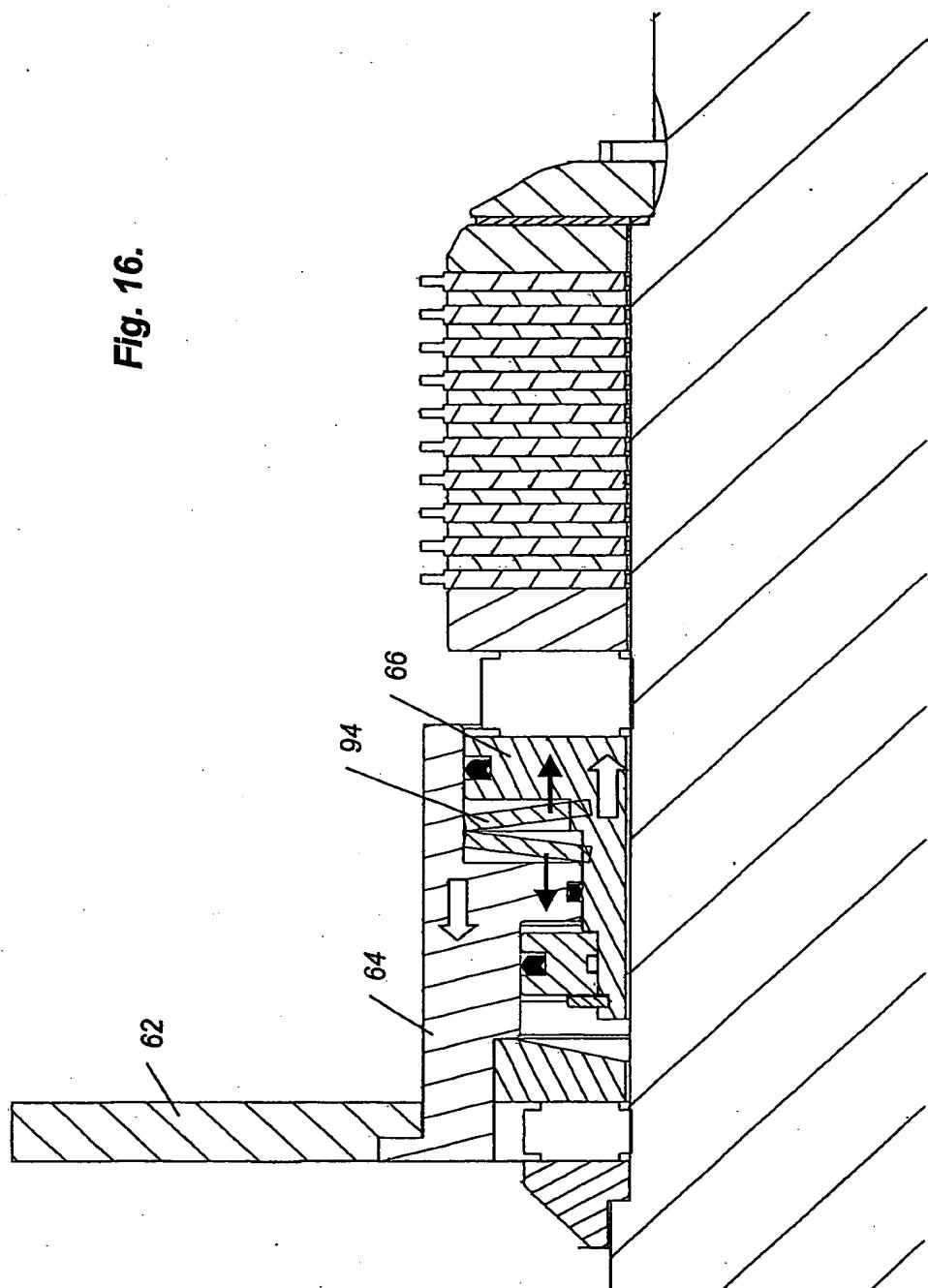


Fig. 16.



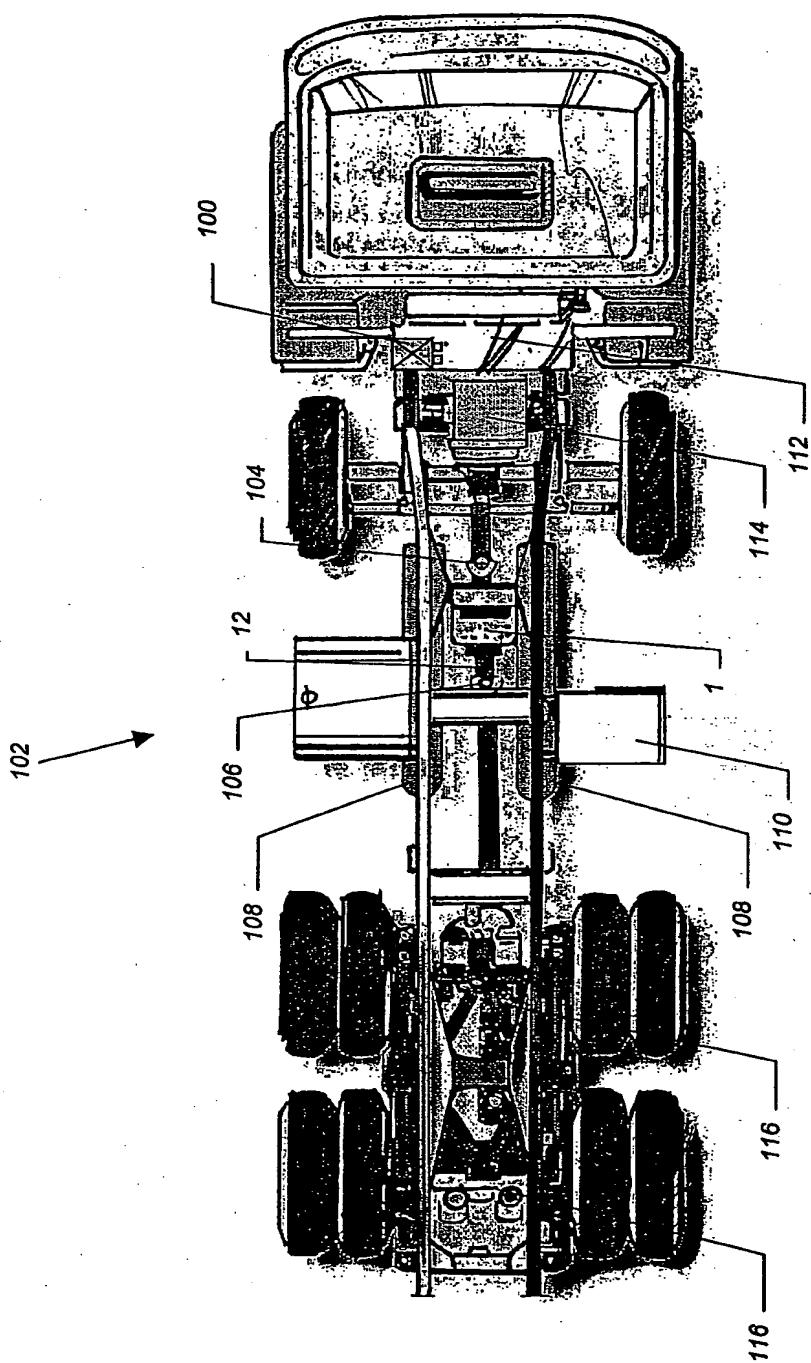


Fig. 17.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU03/00757

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. 7: F01B 3/02; F04B 1/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See below under "Electronic database consulted"

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DWPI : IPC F01B 3/00, 3/02; F04B 1/20, 1/22, 1/30, 1/32, 27/20, 27/22 with "shaft", "disengage" and similar keywords

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99/15790AI (RAUNISTO) 1 April 1999 The whole document	1-11, 18-22 24-36
Y	US 4993780A (TANAKA et al.) 19 February 1991 The whole document	24-36
X	US 4579043A (NIKOLAUS et al.) 1 April 1986 The whole document	1-11, 18-22

 Further documents are listed in the continuation of Box C See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"E" earlier application or patent but published on or after the international filing date

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"O" document referring to an oral disclosure, use, exhibition or other means

"&" document member of the same patent family

"P" document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search 27 June 2003	Date of mailing of the international search report 03 JUL 2003
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU03/00757

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Derwent Abstract Accession No. 97-487615/45, Classes Q12, Q56 JP 09228948 A (CALSONIC CORP) 2 September 1997 Abstract and figure	1-11, 18-22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU03/00757

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member	
WO	9915790	FI	973764
US	4993780.	EP	366080
US	4579043	DE	3338747

END OF ANNEX